THE ALLOCATION OF CHANNELS TO WIRELESS LANS

BACKGROUND OF THE INVENTION

[0001]   The number of channels available to wireless, local area networks (WLANs) is relatively small. In some instances the number of non-overlapping channels (i.e., separate channels) may be much less than ten. For example, among the seven channels specified by

5   the so-called 802.11b standard and allotted by the Federal Communications Commission (FCC) to WLAN usage, only three are non-overlapping. Because the number of non-overlapping channels is so small, it is very difficult to allocate channels to competing WLANs or to various access points (APs) (e.g., a connecting point between a

10   WLAN cell and a wired infrastructure) within one WLAN.

[0002]   Complicating matters further, those channels that have been set aside by the FCC, such as the seven channels mentioned above, are currently unregulated.   That is, though the FCC has allotted certain channels for WLAN usage, it does not decide who can

15   use these channels, or when they can be used. As a result, nothing prevents a source outside the control of a network administrator (e.g., outside the control of the administrative function or entity of a given WLAN) from interfering with users operating over such channels. Still further complicating matters is the fact that this interference is

20   unpredictable.   That is, a given channel may be free of outside interference at one given time, yet may become unavailable due to a high level of interference at another time.   Similarly, for a given channel one segment of a network may be free from interference while another segment is virtually unusable at the same time.   The

25   unpredictable nature of the interference makes it difficult to efficiently allocate a given channel to a network at any given period of time.

[0003]   Another challenge related to the allocation of channels to WLANs is the fact that WLANs cannot make use of existing, so-called hexagonal layouts used by cellular networks. This is because a signal

propagated by a WLAN usually travels entirely indoors compared to a cellular network, where signals travel mostly outdoors. Said another way, because a WLAN generated signal travels mostly indoors, the shape of the cells (i.e., coverage areas associated with each AP) is greatly affected by the internal structure of the building, etc. within which the WLAN is located.

[0004] Because of the high level of interference involved in WLANs, and the unavailability of hexagonal designs, a new framework for allocating channels to WLANs is needed.

SUMMARY OF THE INVENTION

[0005] We have recognized that channels may be allocated to one or more cells within a wireless LAN (WLAN) without causing unacceptable interference by: first, dividing an allocation time period into frames, each frame having a substantially short duration; generating, during each frame, a set of active WLAN cells from the one or more cells based on an allocation vector; and then allocating, during each frame and to each active WLAN cell, one or more channels from among a group of available channels.

[0006] In accordance with the present invention, only those cells allocated a channel may transmit during a given frame. All other cells are prevented from transmitting during the corresponding frame.

[0007] To satisfy the minimum cross-interference requirement, the present invention provides for allocating a channel to the one or more WLANs that satisfy a maximum allowed cross interference given by:

$$a_l^n\left(I_{o,l}^n + \sum_{k=1}^{L} a_k^n \cdot I_{k,l} \right) \le I_l^{\max}, \, n = 1,2,\cdots,N, l = 1,2,\cdots,L,$$

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where L denotes a number of cells, N denotes a number of available channels, $I_{o,l}^n$ denotes an amount of external interference within a channel n to a cell l, a_l^n denotes entries of the channel allocation vector, defined as

$$a_l^n \overset{\text{def}}{=\!=} \begin{cases} 1 & \text{channel } n \text{ is allocated to } l \text{ during the frame under consideration,} \\ 0 & \text{otherwise.} \end{cases} , I_{k,l}$$

denotes the cross interference from cell k to cell l when both cells k and l operate over the same channel, and $I_l^{\max}$ denotes the maximum allowable cross interference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]   Fig. 1 depicts a simplified diagram of a WLAN comprising a number of cells which utilizes methods of allocating channels to cells without causing unacceptable interference according to embodiments of the present invention.

[0009]   Fig. 2 depicts a summary flow diagram of methods for allocating channels to cells without causing unacceptable interference according to embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0010]   The present invention provides for the allocation of channels, in particular radio-frequency (RF) channels, to WLANs. It differs from traditional allocation techniques used in cellular networks in at least three ways.

[0011]   First, the channel allocation techniques provided by the present invention are not guided by hexagonal layouts, even as theoretical starting points.

[0012]   Second, techniques provided by the present invention allocate channels to a WLAN cell dynamically, instead of statically. That is, instead of allocating channels to a WLAN cell for a, relatively

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speaking, long period of time as is done in cellular networks, channels are allocated to a WLAN cell for a substantially short period of time. Such a time period is herein referred to as a "frame". A frame's duration could be as small as a millisecond or a fraction thereof. This

5 length of time is much shorter than the length of time channels are allocated to cells in a cellular network which, at the minimum, might be about the length of time taken up by a cellular telephone call.

[0013] Third, because the present invention provides for the dynamic allocation of channels, it is applicable to situations where the

10 set of channels available for allocation varies with time (depending, for example, on the interference levels from sources outside the control of a WLAN).

[0014] To simplify the explanation of the present invention, the following discussion will assume that a WLAN includes a given

15 number of APs at pre-specified locations. Therefore, in one embodiment of the invention there is no need to determine an appropriate number of APs or locations for a given WLAN.

[0015] To further simplify the explanation which follows, power control problems are not addressed. Instead, in an additional

20 embodiment of the invention, the power levels associated with each AP and its users are assumed to be pre-determined and fixed.

[0016] Because the location of APs and their power levels are assumed to be pre-determined and fixed, it follows that the level of interference attributable to a transmitting AP and its associated users

25 is known in advance.

[0017] Further simplifications may also be made. For example, by assuming that the actual level of external interference received by each WLAN cell and for every channel is known and by assuming that the allocation of channels to a WLAN cannot include altering any

30 user-AP associations (i.e., channels are allocated to WLANs without

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changing, controlling or otherwise influencing the assignment of users to a particular AP), the explanation which follows is simplified.

[0018]   In an ideal network management scenario, because the interference level imposed on a WLAN cell by an external source is

5   potentially time-dependent, this interference information could be determined by ongoing real-time measurements. Such measurements may also be used to more accurately determine the cross interference among WLAN cells as well.

[0019]   Having stated some embodiments based on simplifying

10   assumptions, it should be understood that the scope of the present invention is not limited to embodiments which incorporate these assumptions.   Rather, additional embodiments, realized without taking one or more of these assumptions into consideration, may also be within the scope of the present invention.

15   **[0020]**   Referring now to FIG. 1, there is shown a WLAN 100 consisting of L cells, represented by corresponding access points $l = 1,2,..., L$, where, there are N channels available for allocation by a controller 200 or the like to each cell l, denoted as $n = 1,2,..., N$. The challenge becomes deciding the best way to allocate these channels N

20   to cells L based on some performance criterion.

[0021]   In one embodiment of the present invention, an allocation time period is divided up into frames, each frame having a substantially short duration.   Next, for each frame, a set of active WLAN cells is generated based on an allocation vector, the details of

25   which will be discussed further below. Thereafter, during each frame, a set of channels from among a group of available channels may be allocated to each active WLAN cell. Optionally, the duration of each frame may be substantially the same or different.   The active cells which are allocated a channel are allowed to transmit during a

30   corresponding frame while cells that are not allocated a channel during a given frame (i.e., inactive cells) are turned off for the whole

duration of a given frame. That is, an AP of such a cell and/or its associated users are prevented from transmitting during a corresponding frame. It should be further understood that the sets of channels available for allocation may vary with time.

5 **[0022]** In another embodiment of the invention, during each frame one channel from the set of available channels may be allocated to a cell. However, it should be understood that a given channel may be assigned (i.e., re-assigned) to more than one WLAN cell to overcome channel shortages.

10 **[0023]** Such shortages are due to the fact that the number of channels N is usually much less than the number of cells L. To overcome shortages, the present invention provides for the use of a channel reuse technique (e.g., one channel is allocated to several cells simultaneously). In yet a further embodiment of the present 15 invention, the same channel may be allocated to a number of active cells provided each of the cells allocated the same channel are substantially distant from one another to minimize the amount of cross interference between them (i.e., to ensure the cross interference is tolerable).

20 **[0024]** A formal expression of the requirement that cells be substantially distant from one another to minimize interference when the same channel is allocated to one or more cells involves a discussion of an number of parameters, beginning with I_l^{max}, which is a maximum allowable interference to cell l from all sources. Next, a 25 cross interference, denoted $I_{k,l}$, is defined as the cross interference from cell k to cell l when both cells k and l operate over the same channel. Before going further, it should be understood that by "cross interference from cell k", is meant the interference caused by an AP or a transmitting user within cell k. Similarly, "cross interference to cell 30 l" refers to the interference affecting an AP or a receiving user within that cell.

[0025] In accordance with the present invention, the value of $I_{k,l}$, is determined by accounting for the variability of user locations within cells k and l. That said, the details of this subject are beyond the scope of the invention and are not needed to understand the features of the present invention. It should be further noted that because the transmission power of cells k and l may be different, in general $I_{k,l}$ and $I_{l,k}$ are not equal.

[0026] In addition to interference effects, channel allocation considerations need to be introduced. As explained before, an allocation time period is divided into frames. In one embodiment of the present invention, the period of time of each frame lasts for substantially the same duration denoted by θ and channels may be allocated to each cell at the beginning of each frame. If these time frames are denoted $f = 1,2,3,...$, in one embodiment of the present invention, channel allocation decisions can be expressed by a non-binary L dimensional vector A^f, comprising integer entries a_l^f defined as:

$$a_l^f \overset{\text{def}}{=\!=} \begin{cases} n & \text{channel } n \text{ is allocated to } l \text{ during frame } f, \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

[0027] Alternatively, channel location decisions related to a given channel, n, may be expressed using a binary, L dimensional vector, $A^{n,f}$, comprising entries:

$$a_l^{n,f} \overset{\text{def}}{=\!=} \begin{cases} 1 & \text{channel } n \text{ is allocated to } l \text{ during frame } f, \\ 0 & \text{otherwise.} \end{cases} \tag{2}$$

[0028] A^f is referred to as the "allocation vector" and $A^{n,f}$ is referred to as the "channel allocation vector" (for channel n). It should be noted that a unique correspondence exists between the allocation vector A^f, on the one hand, and the set of channel allocation vectors $\{A^{n,f}, n = 1,2,..., N\}$, on the other hand.

[0029] One last, but not least, vector needs to be discussed. An activation vector, $\hat{A}^f$, is also defined as a vector which specifies those cells that are active, i.e., those that have been allocated a channel, during f. $\hat{A}^f$ comprises entries defined as:

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$$\hat{a}_l^f \overset{def}{=\!=} \begin{cases} 1 & \text{some channel is allocated to cell } l \text{ during frame } f, \\ 0 & \text{otherwise.} \end{cases} \tag{3}$$

[0030] The activation vector is used to generate the active WLAN cells which be permitted to transmit (and by default, the inactive cells that will be prevented from transmitting) during a given frame.

10 **[0031]** One more factor must be discussed before arriving at a maximum cross-interference requirement between cells, namely, the amount of interference to a channel n from external sources that affect a cell l denoted $I_{o,l}^{n,f}$. The superscript f is included to emphasize the time varying nature of external interference. The dynamics of such a variation, however, can be rather slow. In any event, the 15 present invention assumes that prior to each frame, f, an estimation of the external interferences during that frame, $I_{o,l}^{n,f}$, $l = 1,2,...L$, $n = 1,2,..., N$, is available.

[0032] To simplify the notation which follows, so long as it is 20 understood that the discussion which follows relates to a single frame f, the vectors, entries and interferences described above can be expressed as A, a_k, A^n, a_k^n and $I_{o,l}^n$, respectively.

[0033] Using the notation just given, the requirement placed on the maximum cross interference between cells used in allocating 25 channels during each frame f, can be expressed as:

$$a_l^n \left(I_{o,l}^n + \sum_{k=1}^{L} a_k^n \cdot I_{k,l} \right) \le I_l^{\max}, n = 1,2,\cdots, N, l = 1,2,\cdots, L, \tag{4}$$

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where, for the sake of simplicity, $I_{l,l} \stackrel{\text{def}}{=} 0$, $l = 1,2,...,L$. The term a_l^n appears on the left hand side of Equation (4) in order to ensure that, whenever n is not allocated to l, Equation (4) is automatically satisfied.

[0034]   In one embodiment of the present invention, during each frame one or more channels are allocated to cells based on allocation vectors that satisfy Equation (4).

[0035]   Besides being interested in allocation vectors that satisfy Equation (4), it is also desirable to make sure that an allocation vector is maximal, i.e., no additional cells can be activated without violating Equation (4). To ensure that this is so, the present invention places the following additional restrictions on a potential allocation vector.

[0036]   If A and B are two allocation vectors, it can be said that A dominates B if for all channels $n = 1,2,...,$ N, $A^n \geq B^n$, with strict inequality for at least one value of n.

[0037]   In addition, for an allocation vector A to be maximally feasible, or feasible for short, it must satisfy Equation (4) and no allocation vector that dominates it can satisfy Equation (4). The set of maximally feasible allocation vectors is denoted by F, and is called the feasible set.

[0038]   Accordingly, in yet another embodiment of the present invention, an allocation vector is selected, for each time frame f, from among the set of maximally feasible allocation vectors F.

[0039]   We now turn to a discussion of rules and criteria that the present invention may utilize to determine the best allocation vector among all vectors. For example, the present invention may place the following general criteria on the selection of an activation vector.

[0040]   Given some positive weight, denoted w_l, associated with each cell l, channels are allocated according to the following allocation vector:

$$A^* = \arg \max_{\forall A \in F} \sum_{l=1}^{L} \hat{a}_l \cdot w_l. \tag{5}$$

[0041]   Equation (5) may be referred to as a Maximum Weight Channel Allocation rule. In one embodiment of the present invention, Equation (5) is used to identify a best allocation vector from among possible allocation vectors.

[0042]   Although the superscript f is not shown in Equation (5), the weights w_l may vary with time. Accordingly, allocations according to vector A^* may change with time as well.

[0043]   For example, the weights, w_l, may change from frame to frame. Correspondingly, an allocation vector may also be selected on a per frame basis as well.

[0044]   Depending on the cell weights w_l that are used in Equation (5), different allocation policies with potentially different properties will result.

[0045]   For example, in yet a further embodiment of the invention, the weights in Equation (5) may be chosen as $w_l = q_l$, where q_l is the length of the virtual queue of l at the beginning of each corresponding frame f and the virtual queue of cell ℓ is the aggregation of queues of an access point associated with l and users associated with cell l. The resulting policy may be referred to as a Maximum Queue Length Channel Allocation, denoted P.

[0046]   A summary of some of the steps involved in allocating channels to cells without causing unacceptable interference according to embodiments of the present invention described above along with general initiating and reiterative steps are shown in the flow diagram in Fig. 2.

[0047]   One consequence of using the Maximum Queue Length Channel Allocation policy, P, based on Equation (5) where the weights, w_l, are chosen as the length of virtual queues, q_l, is that the

throughput of the WLAN is maximized in the sense that, for a given pattern of traffic arrivals to the system, all of the cell virtual queues will be stable under policy *P*, if they are stable under any other channel allocation policy.

5   **[0048]**   The discussion above has set forth some examples of methods for allocating channels to WLANs without causing unacceptable interference. It should be understood that the controller 200 or a similar device may be operable to carry out each of the features and functions of the methods described above and below
10   using software, firmware, hardware or some combination of the three. Other examples of the inventive methods and controller may also be envisioned. For example, in yet another embodiment of the present invention the period of time associated with each frame may be of a substantially different duration. It is next to impossible, however, to
15   set forth every conceivable example.   Accordingly, additional examples, modifications, etc., that may be thought of by those skilled in the art may remain within the spirit and scope of the parent invention defined by the claims which follow.